International Tsunami Study Team, Samoa, October 2009

Geology Team Preliminary Report 10/22/09

TEAM MEMBERS

Dr. Bruce M. Richmond, Research Geologist, Geology Team Leader
Mr. Mark Buckley, Geologist
U.S. Geological Survey, Pacific Science Center
400 Natural Bridges Drive, Santa Cruz, CA 95060
brichmond@usgs.gov, mbuckley@usgs.gov, Phone: 831.427.4731

Dr. Samuel Etienne, Physical Geographer
Universite De La Polynesie Francaise
Campus D'Outumaoro-Punaauia
B.P. 6570 – 98702 Faa`a Tahiti, French Polynesia
samuel.etienne@upf.pf , Phone 689.803.961

Dr. Luke Strotz, Postdoctoral Research Fellow (Microfossils)
Dr. Catherine Chague-Goff, Research Fellow (Geochemist)
Prof James Goff, Director (Geologist)
Natural Hazards Research Lab and Australian Tsunami Research Centre
University of New South Wales
UNSW Sydney NSW 2052 Australia
l.strotz@unsw.edu.au, c.chague-goff@unsw.edu.au, j.goff@unsw.edu.au

Dr. Kate Wilson, Earthquake Geologist
GNS
PO Box 30368, Lower Hutt 5040, New Zealand
k.wilson@gns.cri.nz, Phone: +64-4-570-4530

Dr. Walter C. Dudley, Professor of Oceanography
Director, Kalakaua Marine Education Center
University of Hawaii at Hilo
200 W. Kawili Street, Hilo, Hawaii, 96720
dudley@hawaii.edu

Mr Faigame "Me" Sale, Technician
Ministry of Natural Resources and Environment, Meteorology Division
PO Box 3020
Mulinu`u, Apia, Samoa
Phone: 20855

Methodology.

The geology team focused on documenting the tsunami geologic signature and the physical processes of tsunami erosion, transport, and deposition of material. Our studies were of two types: 1) reconnaissance site visits where a number of observations and measurements were made in a short time period, and, 2) detailed investigations of selected areas. Appendix I summarizes Geology Team daily activities as reported to the Government of Samoa in UNESCO Samoa ITST Daily Reports.

<u>Reconnaissance site visits.</u> The visits were usually less than one hour and typical observations and measurements made at each site visited include:

-General morphology and characteristics of the coast.

-Observations on the presence or absence of sedimentary deposits and erosional features.

-Inundation and runup measurement(s) using a laser rangefinder.

-Flow depth and wave height if suitable markers could be identified.

-Flow direction indicators (in many areas multiple flow directions were identified).

<u>Detailed study sites.</u> Extended studies of critical sites based on Geology Team reconnaissance and consultation with Samoa Government representatives and members of the ITST. In addition to the data collected in the reconnaissance sites, the detailed studies typically included:

-Topographic mapping using both backpack mounted Differential GPS (DGPS; USGS system; requires post-processing for sub-meter accuracy) and/or a backpack mounted Real Time Kinematic GPS (RTK GPS) system with base station (NZ GNS system). The topographic surveys extended from the nearshore (inner reef flat) landward to beyond the limit of inundation. Survey transects were collected in both shore-parallel and shore-normal lines. Line-spacing density was a function of the size of the study area and time spent at the site. Offshore distance of nearshore surveys were partially controlled by tide stage at the time of survey, with lower tides allowing a greater distance to be traversed. The topographic mapping will be used to characterize the study area and for use in model studies of tsunami wave propagation along the coast.

-Surficial and sub-surface sampling of tsunami deposits. Sub-surface samples were either collected by push cores of plastic pipe, gouge core, Russian peat borer (D-core) or from hand-excavated trenches (Figure 1). Surficial samples consisted of scraping the upper layers of sediment in both subaerial and submarine environments.

Extensive measurements of flow depth and orientation indicators.

Where boulder deposits occurred, boulder size (a,b,c axis), orientation of long (a-axis), and location were recorded.

Material used for identification of tsunami impact characteristics:

Marine material deposited landward (Halimeda clusters, coral debris, microatolls, *Foraminifera* sp., and basalt boulders with marine encrustations.

Transported boulders from shoreline engineering structures.

Wrack (debris) lines of vegetation and human artifacts (clothing, appliances, household items, automobiles, plastic debris etc.).

Ballistic impacts on solid structures such as buildings, trees, and bedrock.

Water-level indicators such as watermarks or debris deposits on suitable surfaces.

Indicators used for specific measurements include:

Flow direction was recorded from a number of field observations and measured by compass (either magnetic or GPS): alignment of bent vegetation (palm trees or coconut trees; figure 2), alignment of collapsed building structure (*fale* pillars or water pipes), alignment of fence posts anchored on the seaside walls of some partially destroyed building, and material such as metal roofing wrapped around tree trunks.

Flow depth was measured with a laser range finder using field evidences such as scratched trunk, bark removal, broken branches, rubbish trapped in branches (figure 3).

Delineation of inundation was made using GPS measurements at the marine water inundation limit. Marine inundation can be recognised in the field by observing the contact between salt-burnt yellow grass and non flooded green grass, limit of debris wrack line, and eyewitness accounts (figure 4).

A boulder field of particular interest was investigated in Satitoa (Aleipata District, east coast Upolu; figure 5). Boulder granulometry was recorded along both transverse and longitudinal profiles, according to field evidence of the tsunami primary flow direction in this area (N340 to N010): *A, B, C* axes and long-axis orientation have been measured. A waypoint was recorded for each measured boulder. We assume that the damaged seawall along the coast road is the source for boulders. Few small rounded boulders were encountered on field, but have been rejected from the collection as they are not the usual material used in seawall engineered structure. They may come from some "marae" encountered in the surveyed area and partially damaged by the tsunami. 160 boulders were measured in this location (see results section).

Commonly measured parameters and their definitions:

Runup – Maximum tsunami water level elevation above mean seal level (MSL, approximate) measured at the landward extent of inundation.
Inundation – The horizontal distance from the shoreline of the maximum inland incursion of the tsunami.
Flow depth – Water elevation above the ground surface at locations along the tsunami pathway.
Tsunami wave height - Water elevation above ~MSL at locations along the tsunami pathway.

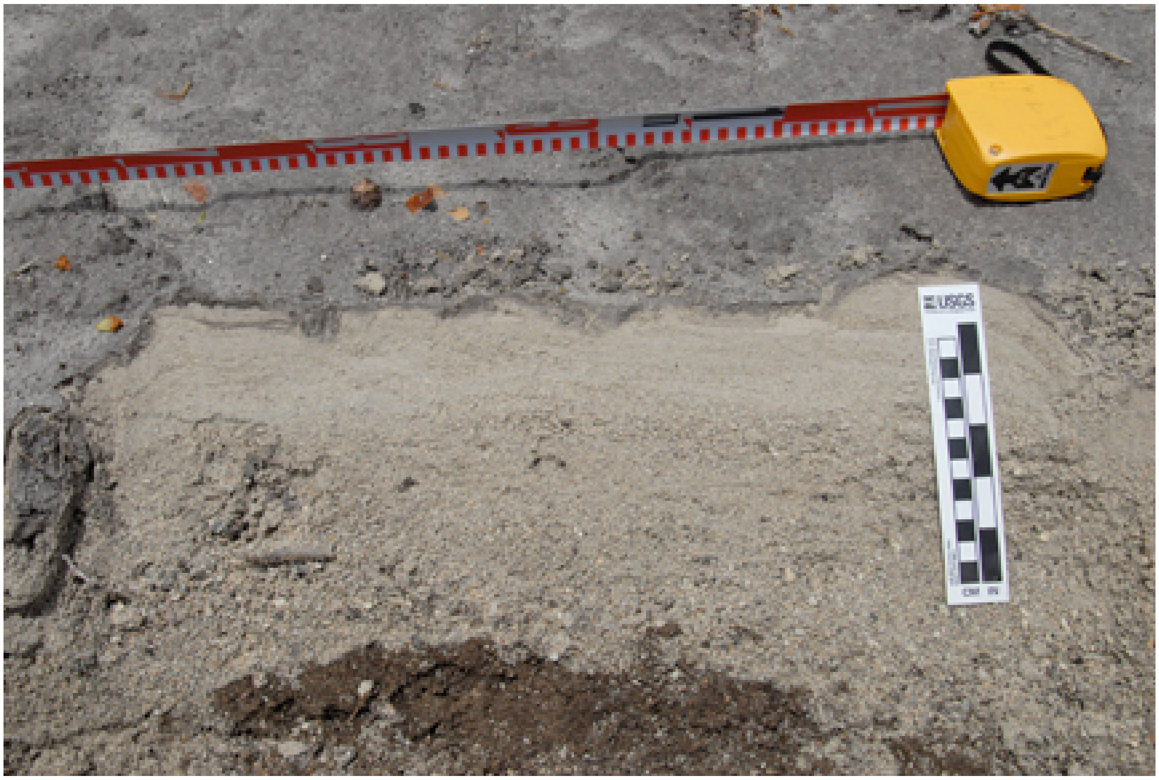


Figure 1. Shallow trench from Satitoa, Alaeipata District on the east coast showing pre-tsunami soil at base with sharp contact to overlying tsunami sand with multiple laminations and capped by a thin mud drape.

Figure 2. Coconut tree trunk used as a flow-direction indicator.

Figure 3. Clothes in a mangrove tree at Vaovai used as evidence for measuring minimum flow depth.

Figure 4. Satitoa, Aleipata District showing vegetation debris rampart composed mostly of tree trunks and branches at the limit of inundation.

Figure 5. Boulder field and sand sheet at Satitoa, Aleipata District. In the background, the seawall behaved as a source for boulders.

PRELIMINARY RESULTS

Figure 6 shows areas traveled and study sites on Upolu for the Geology Team and Figure 7 shows the three sites where extensive surveys were carried out. Appendix II is an MS Excel spreadsheet (incomplete) showing where various types of data were collected. The spreadsheet includes data for boulder measurements, trenches, samples, and water levels. Initials in the spreadsheet database refer to: MB (Mark Buckley) SE (Samuel Etienne), LS (Luke Strotz) and BR (Bruce Richmond). More data will be compiled for a final version of the database. Example topographic profiles in trench sites are shown in figures 8 and 9. Table 1 is a listing of boulder measurements (incomplete) and Figure 10 is a plot showing boulder volume and long-axis orientation for the study site at Satitoa, Aleipata. These figures, tables, and spreadsheet are not a complete listing of all data collected but are meant to show examples of the data collected during the field survey. A more complete compilation will be completed and forwarded to the ITST Samoa for transmission to the Government of Samoa.

Figure 6. Map showing areas traveled (green lines) based on hand-held GPS track logs and areas where mesurements and observations were gathered (white dots). Base map is a Google Earth image.

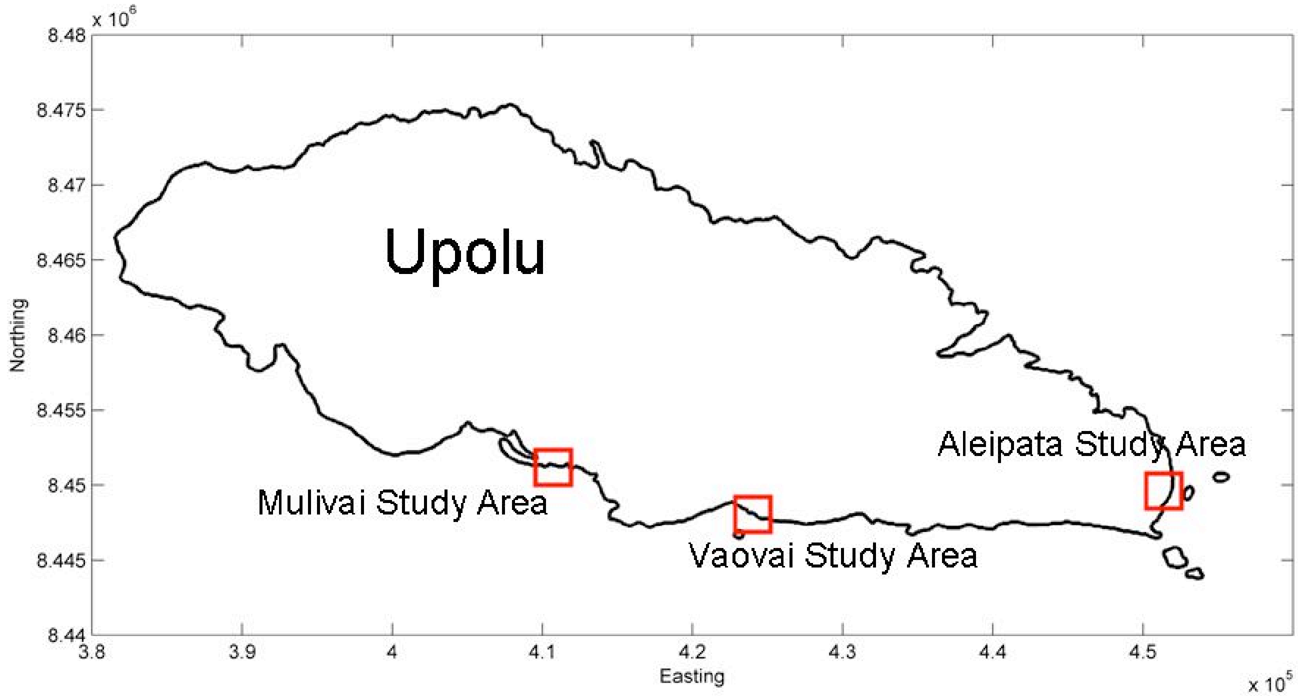


Figure 7. Map showing the location of the Aleipata, Vaovai, and Mulivai detailed study sites.

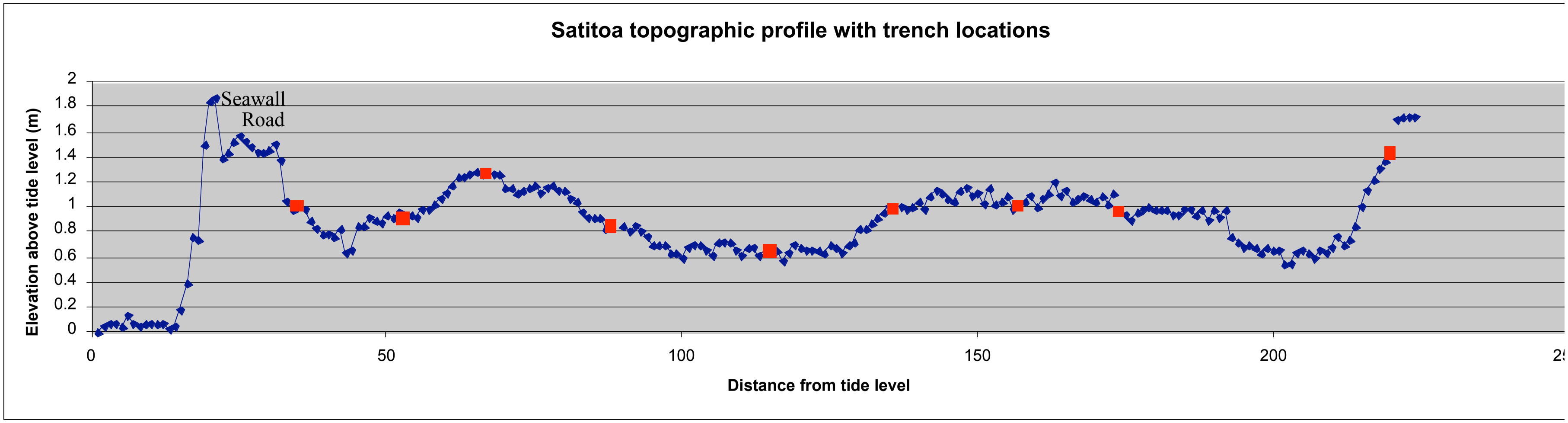


Figure 8**.** Topographic profile along the Satitoa transect. Blue points and line show ground surface. Red points are the locations of trenches examined by the tsunami geology team (starting at T09 on the coast). Profile reaches to the inland extent of inundation. Note the elevations are in metres relative to the tide level at the time of the survey (11.30 am 20th Oct, 2009), the elevations will be calibrated at a later date but the adjustment is expected to be less than 0.5 m.

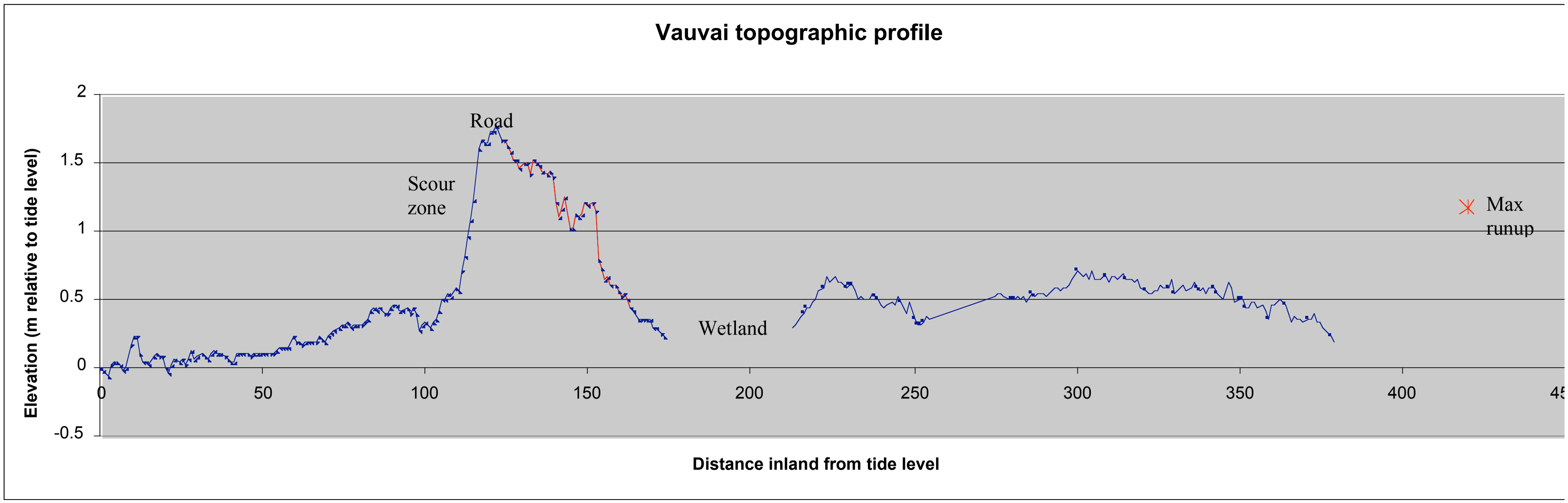


Figure 9**.** Topographic profile along the Vauvai transect. Blue points and line show ground surface (some gaps due to wetland). Red line shows the extent of the sandsheet examined for sedimentary properties by the tsunami geology team (starting at T09 on the coast). The high tide line is at approximately 110 m.

Note the elevations are in metres relative to the tide level at the time of the survey (2:00 pm, 19th Oct, 2009), the elevations will be calibrated at a later date but the adjustment is expected to be less than 0.5 m.

Type of measurement	Number of measurement	Location
Flow depth	**50**	**All**
	29	Satitoa
	7	Siumu
	2	Return to Paradise Beach
	8	Vaovai
	4	Poutasi
Flow direction	**35**	**All**
	23	Satitoa
	5	Malaela
	1	Savau
	2	Siumu
	1	Silanei Reef resort
	3	Vaovai
Inundation limit		
Boulders	**231**	**All**
	160	Satitoa
	67	Vaovai
	4	Savai

Table 1. Boulder measurement data (incomplete) collected by the Geology Team.

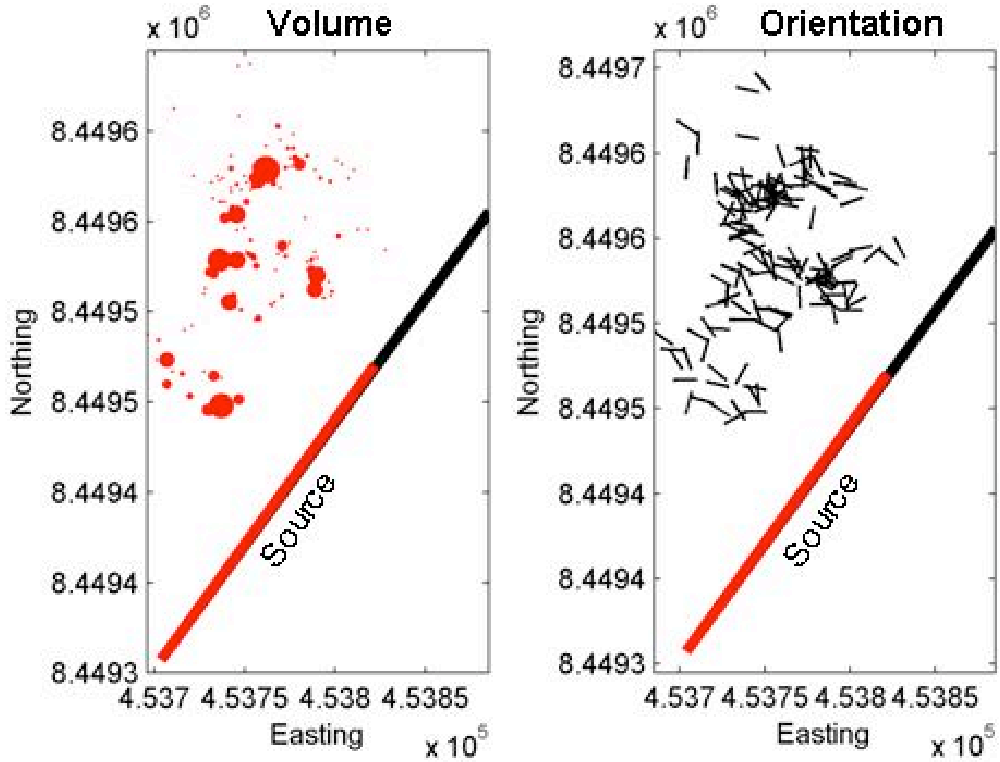


Figure 10. Plots of relative boulder volume (red circles) and boulder long-axis orientation for the Satitoa boulder study site. The red and black lines shows the shoreline orientation and revetment source of the boulders. The black line segment is a section of revetment that showed minimal damage.

Example of a field site description and data collected at one site on 10/14/09

Reconnaissance site visits (pm) to the east and southeast coasts to examine extent of tsunami inundation and impacts and select sites for detailed geologic studies. Accompanied by Fatu Leavasa from the Meteorology Department at Mulinu`u.

<u>Aleipata District, east coast Upolu.</u> Broad low-lying coastal plain bordered by a barrier reef backed by a shallow lagoon. The reef is connected to several offshore islands resulting in a region of complex physiography.

Data collected included:

a) 2 shallow trenches approximately 70 m from the shoreline showing tsunami deposited sand overlying soil and covered by a thin mud drape.
b) Tsunami inundation of about 300 m near Satitoa Village.

c) Flow direction of 314^{o} (towards the NW) along a shoreline oriented roughly N-S (185^{o}).
d) Land surface showing abundant evidence of recent inundation including scoured and eroded soild, deposition of marine debris (Halimeda, fish, etc.), stripped vegetation and massive vegetation debris piles, and widespread destruction of structures.

Lalomanu, SE Upolu. Steep hinterland and narrow coastal plain fronted by a shallow barrier reef (~ 200 m wide).

Data collected included:

a) Preliminary runup (11.06 m) and inundation (143.22 m) using laser rangefinder.
b) Erosional scarp of 1-2 m produced at shoreline probably by return flow.
c) Measurements to the west of Lalomanu were runup (9.19 m) and inundation (23.61 m) along a steep stretch of coast at Cape Tuiolemu.

Vavau (Resort) Area, SE Upolu. Narrow coastal plain backed by cliffs.

Data collected included:

a) Backbeach area severely eroded by return flow.
b) Fale concrete posts show flow direction of 351^{o} (to the NW).
c) Two sites measured for runup (12.06 m, 12.12 m) and inundation (48.64 m, 64.50 m).
d) Beach sand composed of mostly terrigenous sediment with patches of gravel and boulders along base of eroded scarp.

DISCUSSION

The September 29th 2009 left a clear geologic imprint along sections of the east, south, and west coasts of Upolu and the south coast of Savai`i. Geologic evidence of tsunami modification to the coastal zone is in agreement with evidence derived from the other UNESCO Samoa ITST study team findings. Where measurements of inundation and runup were conducted by both the Geology and Inundation-Runup Teams there was good agreement between the types of evidence used and absolute measurement values. Observations by the Structural and Building Impact Team were consistent with the Geology Team observations regarding scour, transport and deposition of sediment, and direction of failure related to tsunami flow directions. Damage to coastal ecosystems and the environment as observed by the Geology and the Ecology and Environment Teams highlight the resilience of natural ecosystems to extreme events.

Key findings of the Geology Team include:

1) In areas where there is a suitable supply of sediment and sufficient tsunami wave forces occurred, tsunami sedimentary deposits are widespread, and for the most part, distinguishable from the pre-tsunami sediment at the ground surface.

a) Areas with sufficient beach sand deposits often produced tsunami sand sheets that filled in topographic lows and thinned on topographic highs. Physical structures, such as walls or stairs, often had thick (10-20 cm) shadow sand deposits in the lee of the structure. In Aleipata sand sheets extended up to ~ 250 m from the shoreline.

b) Mud drapes on the upper surface of tsunami deposits were common and represent fine-sediment deposition from the final stage of tsunami inundation. The largest source of fine-grained sediment is most-likely from soil erosion of the land surface with additional input from either marine or coastal wetland environments. A maximum mud drape thickness of ~4 cm was measured near the limit of tsunami inundation behind Satitoa Village, Aleipata.

c) Internal sedimentary structure of the tsunami sand deposits is complex, showing a wide variation grain size, composition, and number and type of laminations. Internal structure varied with distance from the shoreline and is thought to have recorded complex interactions between wave forces, microtopography, and sediment supply.

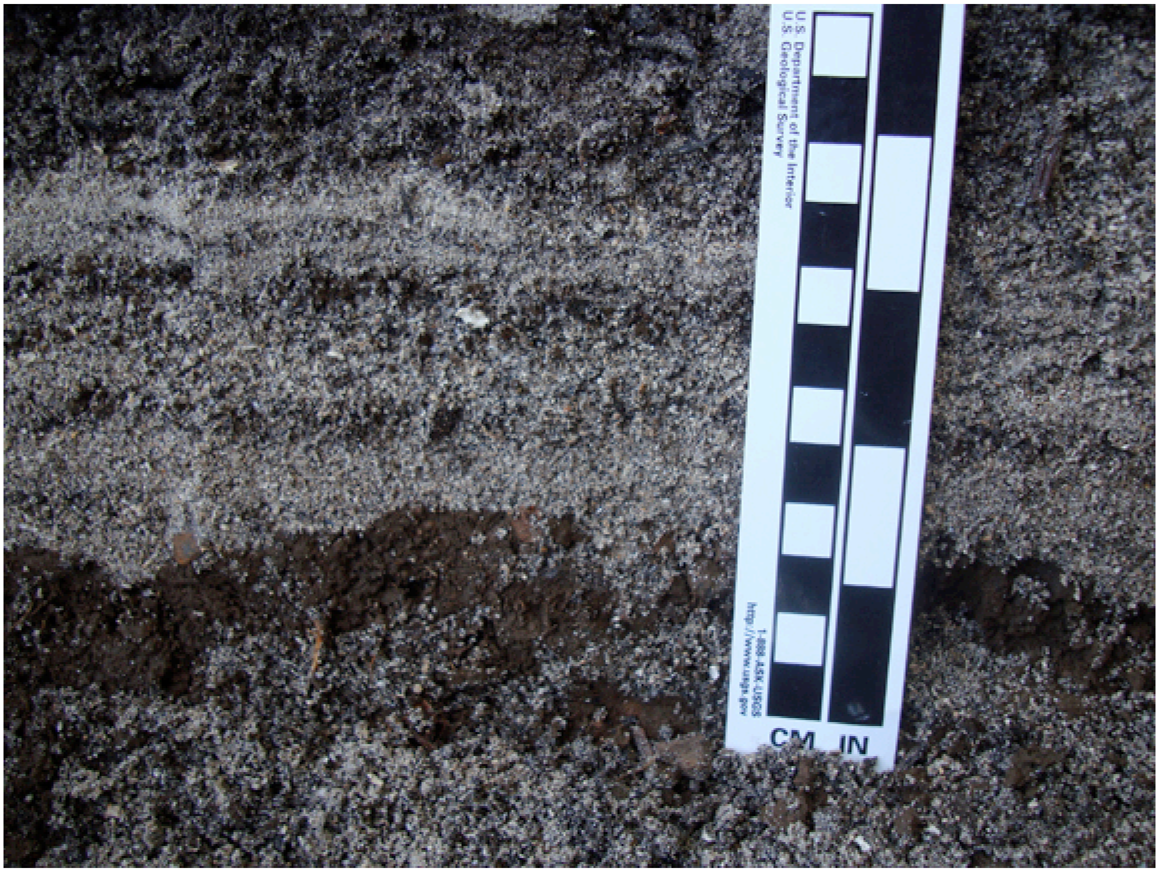


Figure 11. Close-up of a trench face near Satitoa Village approximately 250 m from the shoreline showing, from top to bottom: tsunami mud drape, multiple alternating light and dark layers of tsunami sand, and basal pre-tsunami soil surface.

2) Erosion at the shoreline was widespread and resulted in the transport of sediment and debris in both landward and seaward directions. The shoreline clearly provided sand and gravel (including revetment boulders) to the onshore sedimentary deposits. Maximum erosion of back beach areas, up to ~ 2m, appeared to be driven by offshore return flow of the tsunami in many localities as evidenced by offshore-directed flow indicators associated with major beach scarps.

3) Exploratory trenches in a number of inland sites show the existence of a number of buried sand deposits separated by paleosols. These sand layers very strongly indicate the presence of past extreme wave deposits that deserve further investigation

4) Flow direction indicators often show numerous directions at any one locality and in some cases the relationship between oldest (bottom) and latest (top) gives an approximation of tsunami flow direction through time. The complexity is derived from the interaction between multiple tsunami waves and locally complex topography and bathymetry.

5) Coastal slope has exhibits a strong control on runup, inundation, and return flow characteristics. Steep coasts typically exhibit high runup, limited inundation and strong return flow indicators, whereas low-lying coasts show lower runup, greater inundation, and less pronounced return flow indicators.

6) Maximum transported clast size is dependent upon size of available material. Where coastal protection structures are constructed, mostly of basalt boulders, it is common to find boulders transported inland several tens to ~ 100+ m inland. Automobiles and appliances appear to be particularly amenable to tsunami transport.

7) Wrack lines of thick vegetation debris (vegetation ramparts) are common and occur where landward transport of vegetation of thick debris piles no longer occurs. They are typically seaward of the tsunami inundation line and represent a zone where coastal vegetation significantly retards tsunami flow.

RECOMMENDATIONS

1) The written record of historical tsunamis in Samoa is limited yet it is clear from the tectonic setting of the islands and field evidence from exploratory trenches that Samoa is vulnerable to tsunami impact. A paleotsunami investigation would extend the record of known tsunami impacts back in time and could likely provide useful information on the recurrence interval and magnitude of past tsunamis. This information is critical to tsunami mitigation and planning efforts for developing more disaster resistant communities.
2) Our measurements and observations show highly variable local tsunami impacts as a result of small-scale variations in tsunami flow characteristics. Local topography and bathymetry is a critical element in detailed modelling studies that predict tsunami inundation. High-resolution topographic and bathymetric, such as that derived by airborne lidar, multibeam mapping, or dense ground surveys, would greatly facilitate improved inundation models. Inundation models are are effective means of identifying hazardous areas as a step to improve public safety and infrastructure security.
3) In terms of risk management, the maximum debris wrack line (vegetation rampart) is an important feature to map as marks the limit of greater damage due to pushing and lifting forces of the carried load (mainly trunks and branches, sometimes cars or boats). The maximum debris line is always closer to the coastline than the inundation limit, beyond which inundation can occur but no strong structural damages are expected. In many areas this feature can be mapped remotely by high-resolution aerial imagery.
4) Developing in-country expertise in hazard identification and mapping could improve Samoa’s ability to plan, mitigate, and respond to future hazards. Technical training should be encouraged and supported wherever possible.

Appendix I. Daily reports (unedited) submitted to the Government of Samoa summarizing Geology Team activities.

Wednesday 14th October 2009
A team of geologists worked together to undertake a rapid reconnaissance of the east and south coasts to identify locations that preserve a record of the landscape changes and geological impact and record of the tsunami. Specifically, the team intends to measure and record how the landscape has changed onshore as a result of the tsunami. The geology team had a very good day identifying sites that meet this need. They identified locations where the tsunami eroded sediments at the surface as well as places where it deposited sediment. Such observations are very helpful for understanding past frequencies of tsunamis.

Thursday 15th October 20
Initial work focused on the wharf that has been constructed near the village of Satitoa. Evidence was found that the tsunami had damaged the infrastructure present at the wharf. A large set of concrete steps have been broken away from the end of the wharf, moved across the wharf and lodged beneath metal girders. Scrape marks on the concrete that makes up the wharf indicate that the steps were not fully in suspension whilst being moved and also indicate flow direction. We noted these impacts on structures as they were very clear (even though this team is not focused on building impacts).

The remainder of the day's work focused largely in the area of Satitoa. Here a sizeable sand sheet was identified that is almost certainly of tsunami origin. This sand sheet overlies a hard compacted sand that is dark in colour and is distinctly different from the tsunami deposit. There is a very clear boundary between these two sediment layers.

Seven trenches, located at varying intervals from the coastal strip in a landward direction, were dug to identify the extent of the tsunami derived deposit and any variations in sediment thickness. These trenches revealed that the layer varies in thickness moving away from the coastline. Closest to the road that runs near to the coastline, the layer is between one and four centimetres thick. The layer then thickens up to maximum and ten centimetres and then thins again back to 1-2 cm thickness.

The tsunami sediment layer has clear structure with a number of sub-layers identified. At the base is a layer of coarser material that sometimes contains volcanic pebbles and larger shell material. The upper portion of the layer is overall finer in nature but, depending on location, contains up to six separate layers, with clear variations in sediment character (coarser and finer layers).

The nature of the material that underlies the tsunami deposit (compacted material) suggests the tsunami initially stripped off any sediment that may have previously existed above this compacted sand and then proceeded to deposit the sand sheet. The sub-layers present in the sand sheet suggest the possibility of multiple deposition events (that is, several waves!). Further work in the coming days will continue work on this sand sheet and involve exploration of the southern and south-western coast, looking to identify other sand sheets.

Friday 16th October 2009

Several sedimentological transects were made using DGPS in Siumu on the South Coast of Upolu where inundations of 40 to 150 m, run-up of up to 5 m and flow directions (N10) were observed. Samples have been collected from the reef edge to the most inner inundation line. The area of sedimentation located within the inner part of the reef flat was mapped. Coral tables freshly uprooted and transported by the tsunami waves were encountered in the western part of the reef flat and their location recorded.

At the Sinalei Reef Resort where severe damage to tourist infrastructure was observed (i.e. total destruction of seaside restaurant, nautical activities centre, premium beach bungalows), morphological impacts of the tsunami on the volcanic shore platforms were investigated and measured. We noted that several boulders were transported toward the beach and are good indicators of the incoming flow direction. The resort owners, when asked, told us about their grandmother telling them about the tsunami of 1917. She was living in Apia and saw the water receding and the fish on the beach. She ran uphill and didn't see the wave.

In Mulivai, at the forest fringe, we collected a short core (14 cm in length) of sediment in a marsh and we measured salinity of water. No evidence of sand deposition is present but ponding water was still brackish (3 - 7.4 ‰) despite the heavy rain of yesterday confirming that tsunami waves have reached this area although the vegetation show no signs of salt burning. This confirms that geochemical analysis can provide valuable evidence of past tsunamis within the coastal geological record.

Further west, evidence of inundations (based upon the deposition of and damage to vegetation) were observed and mapped in Lotofaga and Lefaga but no signs of beach erosion or building damage were noted.

Saturday 17th October 2009.

Work again focused in the area of Satitoa. Another sizeable deposit was identified that is certainly of tsunami origin, further confirmed by the fact that the deposit was found on top of the concrete base of a destroyed fale. The deposit consists of a sand sheet that overlies a dark soil that is distinctly different from the tsunami derived deposit with a very clear contact. A boulder field is also associated with this sand deposit.

Over a 225 metre section, ten trenches were put in to examine the nature of the deposit. Each of these trenches was logged and the sand layers were sampled at 1cm intervals in order to obtain any minor structures. A small number of short cores were also collected. The tsunami derived layer has distinct structure and a number of sub-layers identified. The layer is between 7-10cm thick and varies little over the entirety of the 225m section. Sub-layers were less distinct closer to the road and became more distinct as one moved away (possibly due to clean-up operations). At the base of the sand layer is a layer of coarser sand composed of shell fragments and other carbonate material. The upper portion of the layer is finer in nature, but, depending on location, contains a number of separate laminations. These consist of alternating coarser and finer layers some containing basaltic material.

Fifty boulders, emplaced by the tsunami, were measured as part of the analysis of the deposit. Size and orientation of the boulders was measured. The source of the boulders is the seawall constructed along the coastal strip. A full topo-profile was also undertaken to tie in the deposit with local topography.

Monday 19th October 2009

The geology sub team comprised six international scientists and one representative from the MNRE. Today, a 70 m topo-sedimentological transect was completed using an RTK-GPS in Vaovai on the South Coast of Upolu where flow depth was measured at 3.8 m on the seafront and 2.7 m in the mangrove. Flow directions were also recorded. A microtopographical survey of the coastal erosional zone associated with the deposited sand sheet was also undertaken where we collected more than 2100 waypoints. A sand layer up to 20 cm thick composed largely of coarse sand with the upper layer consisting of alternating coarse and thin laminations was described and sampled. The stratigraphy of this layer is comparable to the stratigraphy of the Satitoa deposit.

Five short cores were collected up to 50 cm in length. These largely focus on capturing recent and modern extreme events (tsunami or cyclone) deposits. One of the cores however, contained deposits in the lower portion of the core that may represent a previous extreme event.

Boulder morphometry and orientation were also measured in this area. Two types of boulders have been distinguished: basaltic ones (30 measurements) and coral ones (40 measurements). They are distributed in different areas relative to the coastal road: basaltic boulders represent wash-over of the incoming wave, whereas coral boulders were mobilized by the backwash waves moving rubble material from the roadside filling. These data will be helpful in estimating tsunami flow velocity.

It appears that topographic lows lying behind the coastal road have endured more severe erosion due to an acceleration of the incoming flow. Then, following this erosion phase, these areas have acted as a trap for sediments. Flow depths and orientation were also measured in Poutasi.

Tuesday 20th October 2009

As already mentioned, there are now a moderately large number of geologists still working in the field. As such, they divided in to two separate groups in order to be able to complete more field survey work.

The first geology sub-team spent the day working in the area of Satitoa in the east. The team conducted more detailed field surveys at Satitoa in order to gain a more sophisticated understanding of the lateral extent of sediments deposited by the tsunami.

This took some time since much sediment in close to the settlements has been cleared away as part of the recovery process which is understandable.

A sedimentological transect was completed along the tsunami flow direction, the transect extended 450 m inland indicating that at this location the tsunami inundated at least 450 metres from the shore. Five shallow trenches were excavated at 100 m intervals along the transect. Tsunami sediment varied from 10 cm to 1 cm thickness at the inland limit of inundation.

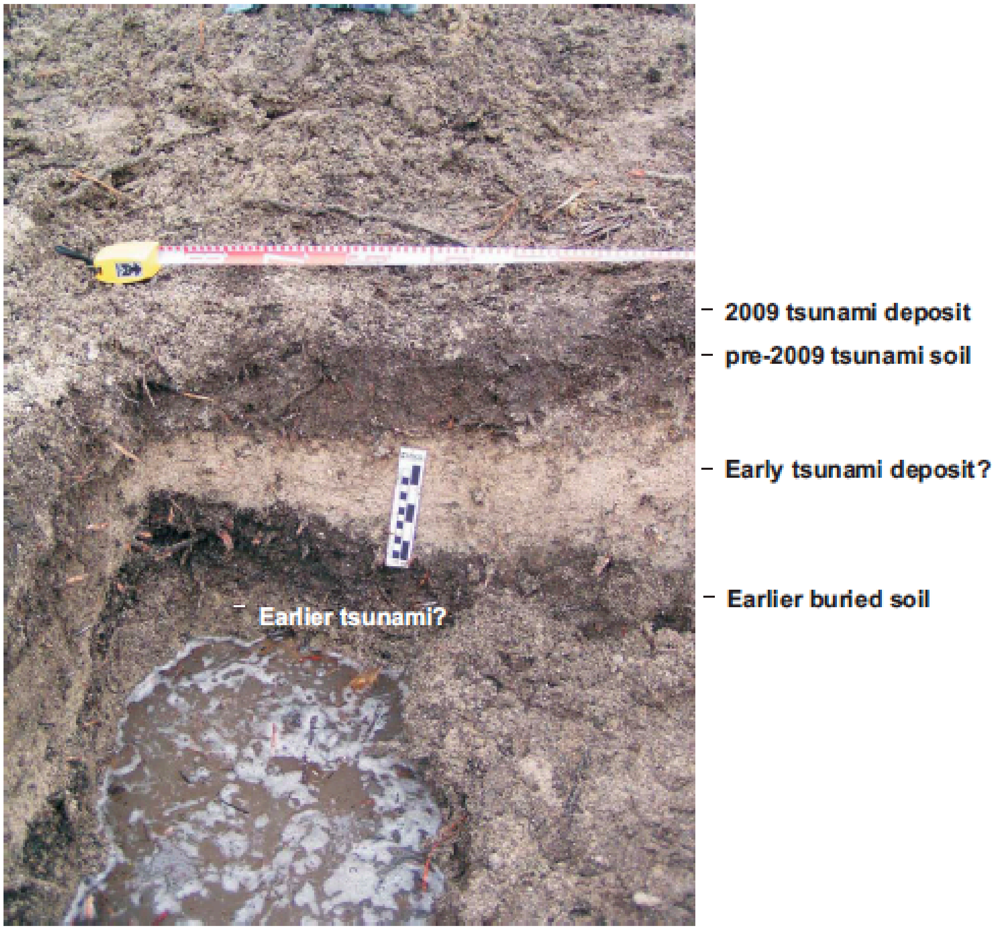
Sediment samples were collected from each trench at 1 cm vertical intervals. The samples will be analysed for microfossil content and grainsize. This information will be used to increase our understanding of tsunami sediment transport and aid in identification and interpretation of prehistoric tsunami deposits. In addition to the surveying of the tsunami sand deposits, boulders transported from the seawall by the tsunami were located. Their dimensions and orientations of were carefully recorded. Coastal boulder deposits have been used to identify past tsunamis and infer tsunami flow velocities and flow depths and can be correlated with building damage levels. A micro-topographic survey was carried out at Satitoa using RTK-GPS. Profiles were taken from the shoreline up to the limit of inland inundation.

The second geology team commenced its ongoing geological survey at the Coconut Beach Resort and travelled west, returning to Apia via the north coast.

Key sites investigated:

- Coconut Beach Resort – A brief reconnaissance of the site, photos were taken of key erosional features and indicators of flow depths before they were lost in reconstruction. Flow depths of at least 3.2 metres were noted.

- Mulivai – a length of coastline extending to about 200 m east of the remains of the Hideaway Resort were studied. Large quantities of dead *Halimeda* (micro algae) and freshly broken coral were found on the beach ridge about 5 metres from the shore indicating recent tsunami inundation. The aim of this reconnaissance was to attempt to find evidence for pre-2009 tsunami deposits. A shallow trench was dug at the maximum easterly extent of the survey but no additional deposits were found. A second trench was dug in a clear area associated with the remains of the Hideaway Resort. A 75 cm deep trench was dug (see Photo) which included an additional two sand layers beneath the 2009 tsunami deposit. The first of these sand layers may be related to either the 1960 or 1917 tsunamis, although there is a well-developed soil which suggests that this may be an older event. This then makes any estimate of the age of the second sand unit beneath the buried soil even harder to determine until we have been able to carry out some dating analyses on these layers.



This was an extremely exciting find and shows us that there are undoubtedly earlier events, although we must stress that until they have been analysed in some detail we cannot definitively state that they are tsunami deposits. An on-site discussion led to agreement that there was a high probability that at least one of these buried sand layers was probably tsunami-related. A core sample was taken so that detailed analyses could be carried out later.

- Safaatoa – Inundation of this area was noted and we measured runup at the site to be 3.20 metres with 13.6 metres inundation distance inland. Numerous coral boulders were noted offshore but discussions with local residents assured us that these were not emplaced by the 2009 tsunami.

- Falelatai – We found no indication of inundation at this location.

- Siufaga – A reasonable amount of inundation was noted here and we recorded about 3 metres of runup, with a maximum inland inundation distance of 49 metres.

A suitable site to the west of the village was identified for trenching, but time constraints prohibited this being carried out today. We did carry out a ground survey of the indicators of runup which included a line of dead *Halimeda* micro-algae coral near the maximum extent of inundation. Seaward of this line was a zone of soil rip-up – when the tsunami waves first came onshore here they eroded the coastline – and only started to deposit material inland on the rip-up line. This line was represented by a line of riped-up blocks of soil that were subsequently deposited some 2-10 metres landward. This type of evidence is a classic indicator of tsunami inundation.

The reconnaissance continued back around the coast to Apia from this point. We had insufficient time to stop for further work, but noted variable degrees of inundation and damage to the far west.

Wednesday 21st October 2009
Significantly, today the geology team took a field trip to Savai'i Island.

The team took the 6am ferry at Mulifanua Wharf and drove west from Salelologa Wharf.

The first place where there was some evidence of tsunami inundation was Satuapitea, where the wave was reported to have reached the house over the road (eye witness account). All has been cleaned up, but salt-burned trees and grass still bear evidence of the tsunami inundation.

In Puleia, the tsunami reached the cliff on the other side of the road. Salt-burned coconut trees, fallen vegetation indicating direction of flow (three directions), and some debris are evidence of the tsunami inundation. Runup was at least 3.2 m above mean sea level (road level), with 2.6 m flow depth at the coconut trees, and the maximum tsunami inundation was 60 m from the shore.

In Gataivai, ripped-up grass is still to be seen on both sides of the road.

At Nuu Black Sand Beach, the team saw fallen palm trees and salt-burned vegetation. There is hardly any sand on the beach itself. However, as the team had not been at this beach before the tsunami, they do not know whether there was sand over the boulders that are now exposed. The maximum inundation was 44 m, with a runup of 5.8 m. Pebbles on sand 'pedestals' of c. 4 cm height suggest recent erosion during the tsunami. Boulders have been plucked off the cliff edge and washed several metres inshore. Sand in the forest area between the road and the beach might have been deposited due to a number of processes, not necessarily the tsunami.

The team also went to the Alofaaga Blowholes, but there was no evidence of any inundation, nor recent shore platform abrasion.

There was no evidence of any tsunami inundation in Siutu, nor Satuiatua. The team then drove to Fogatuli and then turned back.

In summary, there was some evidence of tsunami inundation in a few locations on the south coast of Savaii Island, but no damage. The tsunami seems to have had only minor impact and effect on Suvai'i Island.